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14. ABSTRACT
Four major analyses were conducted using the stable boundary layer JORNADA data. The first was the analysis of the movement of instantaneous plumes released from a spray aircraft and continuously scanned with the lidar. Techniques for quantifying the concentrations of aerosols in the drifting plumes were established. The effects on plume dynamics and spread of short time (~seconds) sub-mesoscale events were quantified. The second was an analysis of “wave modified flux and plume dispersion in the stable boundary layer". We showed that the variances of cross-wind velocities and the turbulence kinetic energy calculated without removing the wave signal are greater than those calculated when the wave signal is

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Report Title

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ABSTRACT

Four major analyses were conducted using the stable boundary layer JORNADA data. The first was the analysis of the movement of instantaneous plumes released from a spray aircraft and continuously scanned with the lidar. Techniques for quantifying the concentrations of aerosols in the drifting plumes were established. The effects on plume dynamics and spread of short time (~seconds) sub-mesoscale events were quantified. The second was an analysis of “wave modified flux and plume dispersion in the stable boundary layer". We showed that the variances of cross-wind velocities and the turbulence kinetic energy calculated without removing the wave signal are greater than those calculated when the wave signal is separated from the turbulence. The third analysis was on the “Stationarity of Sub-Mesoscale Turbulence in the Stable PBL”. We used calculations of the durations of stationarity (D) to derive a new time scale for the persistence of stationarity in the SBL. The fourth analyses separated elevated plume dispersion from plume meander using the lidar data. Dispersion and meander measurements are used to categorization the PBL conditions using the D time scale.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Nappo, C.J., A. L. Hiscox and D. R. Miller, 2008. Wave-Modified Flux and Plume Dispersion in the Stable Boundary Layer. Boundary Layer Meteorology 129:211-223.

Hiscox, April L., David R. Miller, Carmen J. Nappo, James Ross. 2006. Dispersion of Fine Spray From Aerial Applications in Stable Atmospheric Conditions. Transactions of the ASABE 49(5):1513-1520.

Number of Papers published in peer-reviewed journals: 2.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Dr. Carmen Nappo presented a seminars at NCAR, Boulder, Colo. 3-5 Feb 2009, on the Jornada project analysis of stationarity in the PBL.

Dr. David Miller presented a review of the current research in the Jornada project at the ARO program review, 3 Feb 2009.

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
David Miller	0.10	No
Carmen Nappo	0.10	No
April Hiscox	0.00	No
FTE Equivalent:	**0.20**	
Total Number:	**3**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

ARL Stable Boundary Layer Initiative
Grant W911NF-07-1-0066
Final Progress Report
(Aug 1, 2008 – January 15, 2009)

Research Title: **Joint Observational Research on Nocturnal Atmospheric Dispersion of Aerosols (JORNADA)**
Investigators: David Miller, Carmen Nappo
Objective(s): 1. to analyze and quantify the nocturnal PBL structure, its dynamics, its turbulence, its wave structures and the effects of these on plume dispersion and meander. 2. To utilize the unique continuous lidar measurements of elevated plume dynamics to identify and quantify physical processes in NBL.

Research Progress: July 2008-January 2009

Objective 1.

Analysis of the Stationarity of Mesoscale Turbulence in the Stable PBL:

Work continued this period on the analyses of the stationarity of the 90 sec averages of σ_w, σ_v, *TKE*, θ (horizontal wind direction), and *U*. The persistence of these 90 sec values we call submesoscale stationarity, which we take to be analogous to turbulence stationarity. We use calculations of durations of stationarity (D) to quantify the persistence as explained in the August 1, 2008 report on this project. Table1 lists the 50 and 90 percentile nightly durations of the above parameters. Note that the values of D are weakly dependent on height, are not the same for each parameter, and vary from night to night. Some effort was made to combine D with other time scales to establish a non-dimensional scaling parameter. But the efforts to date have added complexity but did not add information. Therefore we are using the durations directly as the time scale of submesoscale turbulence.

In summary, the analyses have shown D has the following characteristics: the cumulative probability distributions of D are independent of height as shown in Figure 1. The length of durations of the various parameters are related to the relative importance of the submesoscale forcing. We used the nightly average value of Wind Speed (U, m/sec) to represent the overall mesoscale forcing across the region. Then we compared the nightly 50% probability, submesoscale durational time scales variations as a function of wind speed. All the average nightly durations generally decreased as a function of increasing wind speed except the duration of D(U), which was close to constant over the range of wind speeds encountered. TKE, a three dimensional quantity, generally had the longest duration time. θ also showed relatively long durations across all wind conditions. σ_w, generally had the shortest durations during the low wind conditions but reversed to long durations on the high wind speed day. These patterns were most dependent on the submesoscale fluctuations during the night. Rapid fluctuations resulted in short durations, and slow fluctuations resulted in longer durations.

Most recently, the above analyses were repeated but instead of using 90 s averages, the nightly-averaged local-turbulence integral time scales were used. The integral time scale is defined as the time lag for the autocorrelation of vertical velocity to go to zero. These values ranged from about 85 s at 1.5 m to about 55 s at 11m. Using these values, D show a decrease with height, and these decreases are correlated with the nightly-average wind speed.

Objective 2.

The JORNADA data set includes simultaneous micrometeorological measurements of the boundary layer structure, turbulence, and wave activity along with continuous lidar measurement of aerosol plume releases. What makes JORNADA unique is the real-time monitoring of an elevated plume with a lidar. For the first time, we can see actual plume dispersion for extended periods of time. Plume behavior is examined in two different categories below: plume meander (movement) and plume dispersion (spread). Prior work has developed techniques for determining plume dispersion parameters (Hiscox et al. 2006a) and plume concentration (Hiscox et al. 2006b) to help merge the lidar and micrometeorological measurements. The application of these techniques to the JORNADA data allows for a more complete understanding of the nocturnal boundary layer (NBL). We have analyzed lidar measurements of plume meander and dispersion and their relationship to the complexities of NBL structure.

Plume Dispersion:

Vertical plume dispersion parameters (σ_z) were derived following the methods of Hiscox et al. (2006a) (Figure 2 a.) resulting in a time series of near instantaneous dispersion. Lateral dispersion parameters (σ_y) are also of interest, but cannot be found without first performing an angular correction to the lidar data. This correction is necessary to correct the plume width. Because it is impossible to measure the true cross-wind width by maintaining a single lidar azimuth angle, the raw measurement of Δy is will over-estimate the lateral spread. Figure 2 b,c diagrams the corrections. Once the correction is made, the true Δy is used to calculate σ_y following the same procedure as for the vertical dispersion parameters:

$$\sigma_y = \sqrt{\frac{\left(\frac{\Delta y}{2}\right)^2}{-2\ln(\alpha)}}$$

where, Δy is the corrected plume width (figure 2a) and α is the ratio of maximum lidar backscatter to plume edge backscatter. All plume parameters were found for each individual slice and then averaged to form the 90-second values.

Figure 3 shows the time series of vertical dispersion along with the corresponding wind speed and direction measurements for each of the four nights. Figure 4 shows the same for lateral dispersion.

There are several general characteristics of plume dispersion that become apparent when examining the time series. Most notably that the night of April 28th exhibits a steady, nearly constant plume spread in both the vertical and horizontal directions throughout the night. The plume shape on this night is also nearly round with an average σ_z to σ_y ratio of 0.8 with a standard deviation of 0.3. Very little of the classically predicted nighttime "fanning" is observed on the 28th. The other three nights, however, exhibit lower wind speed conditions with rapidly changing wind directions. These three nights all have flattened plumes (nightly mean σ_z to σ_y ratios of 0.37, 0.28, and 0.34 on the nights of April 22nd, 26th and 27th respectively) as would be expected under nighttime conditions where vertical motion is suppressed and horizontal motion is not. It can also be noted that plume spread in both the horizontal and vertical direction increases when wind speed decreases. This is most noticeable on the night of April 22nd around 4:00 am.

Comparisons were made to the on-site dispersion algorithm presented in Irwin (1983) and Draxler (1976). This model offers a method of predicting dispersion from plume travel time and variation of wind speed.

$$\sigma_z = \sigma_w T f_z$$

$$\sigma_y = \sigma_v T f_y$$

where, σ_w and σ_v are the standard deviations of the horizontal and vertical components of the wind respectively, T is the down wind travel time of the plume and f_z and f_y are non-dimensional functions of travel times derived from a wide range of observations taken in the 1950's and 1960's and for an elevated release under stable conditions are given by:

$$f_z = \frac{1}{1 + 0.945\left(\frac{T}{100}\right)^{0.806}}$$

$$f_y = \frac{1}{1 = 0.9\left(\frac{T}{1000}\right)^{0.5}}$$

σ_w and σ_v were found directly from the sonic anemometer data at the 10 meter measurement height based on the 90 second averaging time, with each averaging period starting at the same time of the initial lidar slice for the same 90 second period. T was found from the average wind speed for the same period and the average downwind distance, X, as found from the lidar as discussed above. Figure 4 and 5 present the comparison of these predicted values to the measured values from the lidar for the vertical and horizontal directions.

Overall the traditional model was not a good predictor of the plume dispersion measured by the lidar. In all cases there is a much larger variation in the modeled values than those measured. These results were expected and demonstrate the lack of accuracy of traditional plume modeling schemes in the PBL where the duration of stationary conditions is quite short. The model above was derived using long time averages (1hr), and therefore combines meander motions in the dispersion coefficients.

Plume Meander:

Figures 5 and 6 show movements of the plume center line in the vertical and horizontal planes respectively. Three nights (22, 26, 28) are shown which span the general conditions encountered with average wind speeds of 1.6, 1.4, and 4.9 m/sec. In Figure 5 the average 50% probability durations of the vertical velocity variations are shown with time series of σ_z throughout the 5 hour period. Note that the lowest durations correspond with the high wind speed day which had fast, but relatively small, vertical fluctuations of plume centerline height. Whereas the two “quiet” nights had much longer durations. The horizontal meanders, shown in Figure 6, demonstrated a similar relationship with the durations of wind direction (θ). The high wind speed day with rapid, small fluctuations in wind direction showed the lowest the durations, whereas the day with the slowest and longest horizontal fluctuations showed the highest durations.

Literature Review: A comprehensive review of the previous work on “Atmospheric Turbulence and Diffusion Estimates Derived from Plume Image Analysis” was prepared and presented at the AMS Air Pollution Conference Session honoring Frank Gifford (Nappo et al, 2008). The review examined the previous work and explained how the lidar imaging work in the JORNADA experiment is a logical and important continuation.

Continuing Research:

Currently we are continuing to analyze the correspondence of Ds with the measured plume dispersion and meander. Our objective here is utilize D as a time scale to order the plume movements. We will continue to analyze different ideas to quantify and visualize plume meander and dispersion from the lidar data.

We propose to parameterize a local lagrangian transport model (Wang et al. 2008) with the duration time scale, and test it against our lidar measurements of the elevated plume.

We propose extending this research to larger data sets by conducting these duration of stationarity analyses on the CASES-99 tower data.

References

Nappo, Carmen J., David R. Miller and April L. Hiscox. 2008. Atmospheric Turbulence and Diffusion Estimates Derived from Plume Image Analysis. AMS conference on Air Pollution Meteorology, Frank Gifford Memorial Session. January 2008.

Hiscox, April L., Carmen J. Nappo, David R. Miller. 2006 a. “A Note on the use of lidar images of smoke plumes to measure dispersion parameters in the stable boundary layer”, Journal of Oceanic and Atmospheric Technology, vol. 23, no. 8, 1150–1154.

Hiscox, April L. and David R. Miller. 2006 b. “Dispersion of fine spray from aerial applications in stable atmospheric conditions”, Transactions of the ASABE, vol 49, no 5, 1513-1520.

Irwin, J. S., 1983: Estimating Plume Dispersion--A Comparison of Several Sigma Schemes. *Journal of Climate & Applied Meteorology*, American Meteorological Society, 92.

Wang, J., A. L. Hiscox, D. R. Miller, and T. W. Sammis. 2008. A Dynamic Lagrangian, Field-scale Model of Dust Dispersion from Agriculture Tilling Operations. ASABE Transaction. In press. Anticipated publication in: Transactions of the ASABE 51(5) 1763-1774.

Publication:

C. J. Nappo, A. L. Hiscox and D. R. Miller, 2008. Wave-Modified Flux and Plume Dispersion in the Stable Boundary Layer. *Boundary Layer Meteorology* 129:211-223.

Seminars:

Dr. Nappo presented a seminars at NCAR, Boulder, Colo. 3-5 Feb 2009, on the Jornada project analysis of stationarity in the PBL.

Dr. Miller presented a review of the current research in the Jornada project at the ARO program review, 3 Feb 2009.

Papers in Preparation:

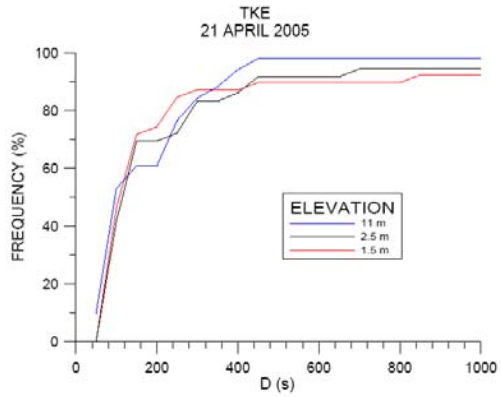
Nappo, Miller, and Hiscox: An analysis of the stationarity of sub-mesoscale flow in the stable boundary layer. (for submission to BLM)

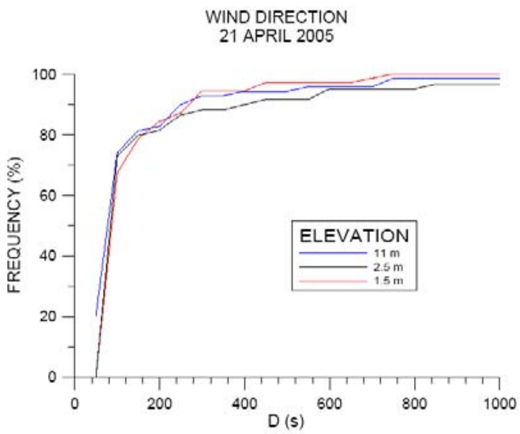
Hiscox, Miller and Nappo. 2008. Plume Meander and Dispersion in the Nighttime Stable Boundary Layer. (for submission to BLM).

TABLE I. Stationarity in minutes at 50 and 90 percentile

		1.5 m		11 m	
April		**50 %**	**90 %**	**50 %**	**90 %**
20-21	σ_w	2.64	7.60	3.50	11.64
	σ_v	2.50	5.72	3.30	11.47
	TKE	2.42	5.47	4.49	14.68
	U	2.46	4.96	3.91	10.87
22-23	σ_w	3.18	7.75	2.33	5.42
	σ_v	2.19	4.29	6.30	16.08
	TKE	2.33	6.14	7.16	25.81
	U	2.78	6.54	3.51	12.43
25-26	σ_w	4.42	15.78	2.35	6.03
	σ_v	2.75	5.79	3.75	8.69
	TKE	2.62	6.25	7.67	22.62
	U	2.51	5.04	3.48	12.05
26-27	σ_w	4.88	11.54	1.82	6.03
	σ_v	2.92	7.11	2.70	9.36
	TKE	2.35	5.28	7.51	23.21
	U	2.57	5.87	3.54	7.48
27-28	σ_w	3.64	8.00	2.68	7.38
	σ_v	2.54	8.37	2.08	9.58
	TKE	2.70	7.81	2.65	10.57
	U	2.92	6.89	2.14	5.74

Figure 1.
Cumulative frequency distributions of Durations of Wind Direction, Wind Speed and TKE, 0100 – 0600 21 April, 2005.





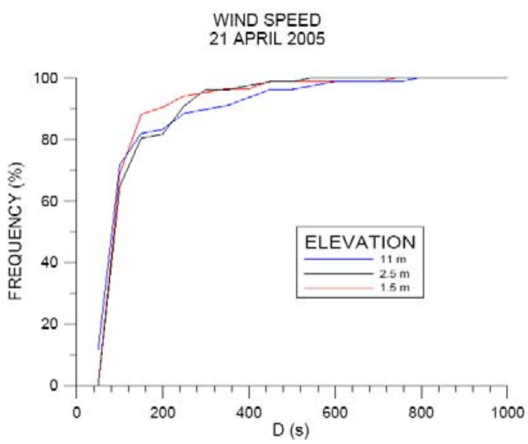
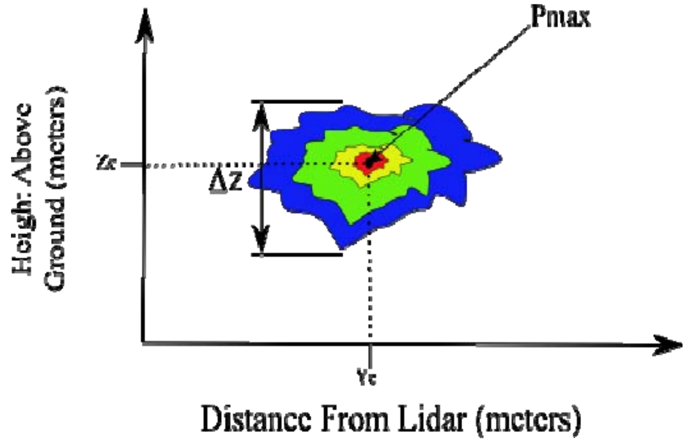
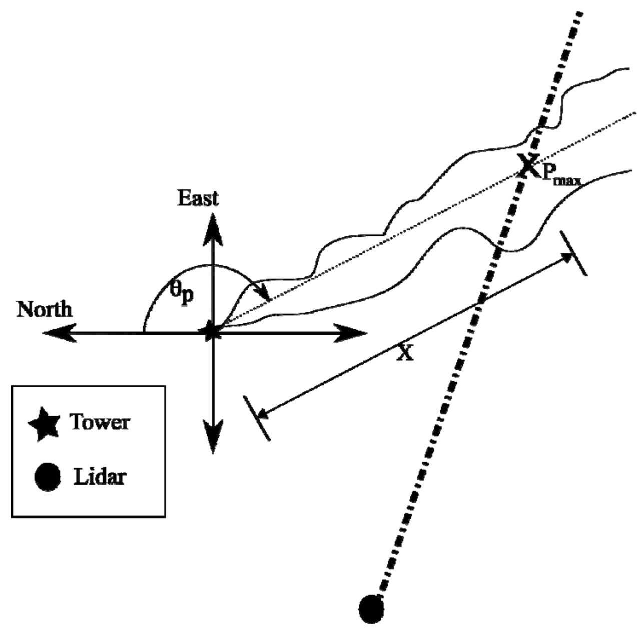


Figure 2: (a) schematic of a lidar plume cross section. Pmax= location of maximum lidar backscatter. Zc= height above ground, Yc= horizontal distance from lidar to plume max. (b). Schematic of lidar-plume measurement looking down from above: The bold dash-dot line represents the lidar measurement slice. Pmax is the location of maximum backscatter as measured from the lidar (see panel a). The dotted line is the plume axis and it represents the predominant plume direction from the release point to the measurement point. The downwind distance of the measurement X is taken to be the straight line distance from the tower to Pmax. The plume angle θp is the angle between north and the plume axis. (c) Relationship of true horizontal plume width (solid line) to measured plume width (Dash-dot line).





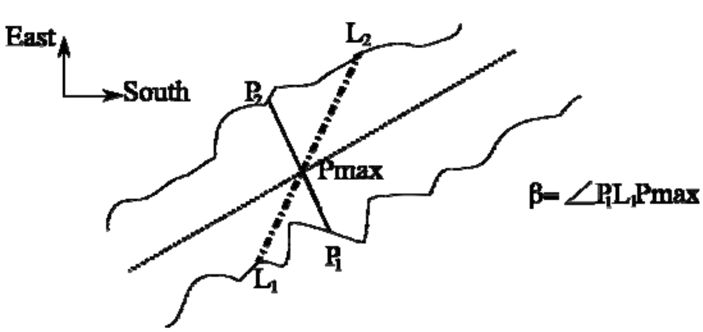


Figure 3. Vertical Lidar-Measured Dispersion Parameters with Winds at 1m and 1.5m.

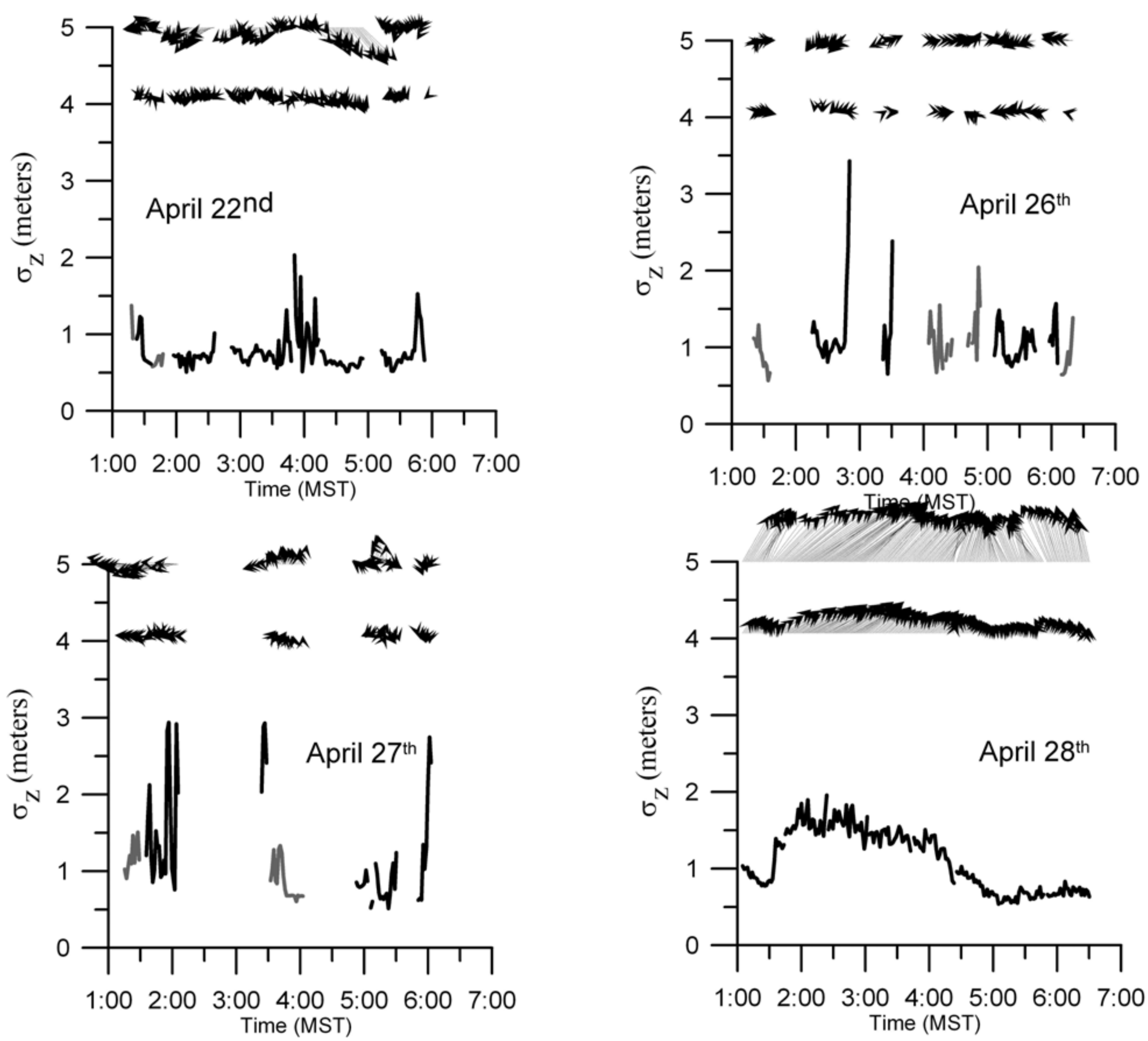


Figure 4. Lateral Lidar Measured Dispersion Parameters